NACA

RESEARCH MEMORANDUM

RESULTS OF FLIGHT TESTS TO DETERMINE DRAG OF PARABOLIC

AND CONE-CYLINDER BODIES OF VERY LARGE FINENESS

RATIOS AT SUPERSONIC SPEEDS

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SUMMARY

Results of a free-flight investigation at supersonic speeds to deter-
mine zero-lift drag of a series of bodies of revolution are presented.
Configurations tested included two parabolic bodies with fineness ratios
of 17.78 and 24.5 and two 8° cone-cylinder bodies with fineness ratios
of 17.2 and 21.2. Results of previous tests of similar parabolic bodies
but with lower fineness ratios are included in this paper for comparison.
All bodies for which data are presented in this paper had a base-to-
maximum-diameter ratio of 0.437. Calculated drag coefficients are shown
for all bodies for which data are presented.

For supersonic speeds, parabolic bodies having nearly optimum
location of maximum diameter (0.6 body length) have minimum drag coeffi-
cients (based on frontal area) at values of fineness ratios from 9 to 18.
This drag coefficient is approximately 0.14. With fineness ratios in
the range of 17 to 25, parabolic bodies have between 9 and 18 percent
less drag than 8° cone-cylinder bodies having the same volume and
maximum diameter.

INTRODUCTION

The Langley Pilotless Aircraft Research Division of the National
Advisory Committee for Aeronautics is currently investigating the zero-
lift drag of bodies suitable for fuselages of transonic and supersonic
aircraft. The experimental results of one phase of this investigation
dealing with effects of fineness ratio and position of maximum diameter
on the drag of parabolic bodies have been reported in reference 1.
Consideration of these results indicated that, for a given volume, the
minimum drag would be obtained with fineness ratios in excess of 12.5,
the maximum fineness ratio used in the tests of reference 1. Tests were

therefore made to determine the zero-lift drag of parabolic bodies having larger values of fineness ratios (17.8 and 24.5). Two cone-cylinder bodies of fineness ratios 17.2 and 21.2 having the same volumes as the parabolic bodies with fineness ratios of 17.8 and 24.5, respectively, were also tested to obtain a comparison between the drag of parabolic bodies and the drag of the more easily constructed fuselage shapes. The results of these tests are reported herein and are compared with those of reference 1 and with calculated results.

The free-flight tests were conducted at the Pilotless Aircraft Research Station at Wallops Island, Va. The Mach number range was from 0.95 to 1.7 and the range of the corresponding Reynolds numbers based on body length was from 40×10^6 to 155×10^6.

SYMBOLS

C_{D_A} drag coefficient based on body frontal area

$C_{D_V}2/3$ drag coefficient based on volume$^{2/3}$

C_{P_B} base pressure coefficient

L/D fineness ratio

L length of body, inches

D maximum diameter of body, 7.5 inches

M Mach number

R Reynolds number based on body length

K position of maximum body diameter as fraction of body length

d body diameter at station x, inches

x variable distance along body axis from nose, inches

Estimated drag coefficients are listed in the following component parts:

P_N pressure drag of nose section of body

P_T pressure drag of entire body

F . fin drag

B   base drag

V   viscous drag

MODELS AND TESTS

The general arrangement for the four test models used in this investigation are shown in figure 1 and photographs of the models are shown in figure 2. All four models were made of wood and finished with clear lacquer. Their maximum diameters were 7.5 inches and their base diameters were 3.28 inches.

Two of the bodies tested were cone-cylinder types of bodies, their profiles being formed from the revolution of straight-line elements. Both cone-cylinder bodies had 8° conical noses, cylindrical midsections, and cut-off conical afterbodies; they differed only in length of midsections. These bodies were chosen for the present investigation as they represent easily constructed and practical shapes. The specific proportions of the bodies were ascertained from considerations of structure and from calculations of least drag for a given volume and diameter.

The other two bodies tested were slender bodies of parabolic-arc profiles similar to the bodies tested in reference 1 and had positions of maximum thickness at 0.6 body length. They are near optimum for parabolic bodies with respect to minimum drag for any given volume. The equations of their profiles are as follows:

$$0 \leqq x \leqq 0.6 \, L, \quad d = D - \frac{D}{K^2}\left(K - \frac{x}{L}\right)^2$$

$$0.6L \leqq x \leqq L, \quad d = D - \frac{0.5627 \, D/2}{(1 - K)^2}\left(\frac{x}{L} - K\right)^2$$

The dimensions of the bodies tested are given in the table below:

Profile	L (in.)	L/D	Volume (cu in.)
Cone-cylinder	129.1	17.2	3512
Parabolic	133.2	17.78	3512
Cone-cylinder	159.1	21.2	4941
Parabolic	183.8	24.5	4941

As the table indicates, the shorter bodies were of equal volume as were the two longer bodies. All models were stabilized by three 45° swept fins with total exposed area of 1.69 square feet, each having a streamwise chord of 9 inches. The duralumin fins had thickness ratios of 0.028 and were located on each body so that their trailing edges intersected the body at the 90.53 percent station.

The two parabolic bodies were equipped with telemetering instrumentation by which base pressures were obtained. The pressure-pickup orifice of each model was located in the rocket blast tube (see fig. 3). A pressure-check valve was used so that rocket-case pressures would not be measured during the burning period in order to keep the range of the pressure cell at a minimum.

The models were propelled by a two-stage rocket arrangement. The first stage was a high-velocity aircraft booster rocket equipped with four fins; the second stage was a rocket contained within the model.

Test data were obtained and reduced by the methods described in reference 2. The velocity was obtained from the CW Doppler radar set; base pressures from a telemeter instrumentation unit; and the trajectory and atmospheric data from an NACA modified SCR-584 tracking radar unit and radiosonde observations, respectively. The measured drag represents the drag of the total configuration and includes the fin and fin-body interference drag.

In figure 4 the Reynolds number during flight, based on body length, is plotted against Mach number for each body tested.

The accuracy of the tests is estimated to be as follows: drag coefficients within ±0.01 at M = 1.0 and ±0.005 at M = 1.4; base pressure coefficients within ±0.015 at M = 1.0 and ±0.007 at M = 1.4; and Mach number within ±0.01.

RESULTS AND DISCUSSION

Parabolic Bodies

The variation of total drag coefficient, base pressure coefficient, and base drag coefficient with Mach number for the two parabolic bodies tested is shown in figure 5.

The base pressure coefficients indicate greater suction on the base of the longer body and show little variation with Mach number at supersonic speeds. The base drags are approximately $2\frac{1}{2}$ percent and 9 percent of the total drags of the bodies with fineness ratio of 17.8 and 24.5, respectively, at supersonic speeds.

A summary plot of the total drag of parabolic bodies is shown in figure 6 and includes the drag of the three similar bodies of lesser fineness ratios previously presented in reference 1. The results shown in this figure indicate that the bodies having fineness ratios between 9 and 18 have the least drag and almost equal drag throughout the supersonic speed range of the tests.

The calculated and experimental variation of drag coefficients with fineness ratio at $M = 1.4$ for the parabolic bodies is shown in figure 7. When the calculated drag was determined the pressure-drag component was calculated by the linearized theory of reference 3. The fin drag coefficient of 0.055 used was an experimental value obtained from flying the same type of fins used in this investigation on a cylindrical body for which the body drag was known. The base drags of the two bodies with higher fineness ratios were obtained in the present tests; whereas those of the three bodies with lower fineness ratios were determined from the unpublished data of previous tests. Viscous drag coefficients, based on wetted area, ranged from 0.0017 to 0.0020 and varied with Reynolds number as calculated by reference 4. Of the component parts of the total calculated drag, viscous drag at higher fineness ratios represents the largest portion, being approximately 55 percent of the total drag for the longest body. When it is considered that the tested bodies have near-optimum locations of maximum diameter (0.6 body length), as concluded from reference 1, 0.14 represents the approximate minimum drag coefficient for finless parabolic bodies of revolution. This statement has been found to hold over the supersonic Mach number range of the tests.

Cone-Cylinder Bodies

Experimental drag coefficients, based on frontal area and plotted against Mach number, of the two cone-cylinder bodies tested are shown in figure 8. As the different fineness ratios were attained merely by altering the length of cylinder used, the fairly constant difference in the drag of the two models can be largely accounted for by the additional viscous drag of the longer body.

The variation of experimental and calculated drag coefficients based on frontal areas and plotted against fineness ratio for the cone-cylinder bodies at $M = 1.4$ is shown in figure 9. When the calculated drag was determined, the pressure drag and viscous drag on the cone-cylinder bodies were obtained by the methods of references 3 and 4, respectively. The same experimental value of fin drag that was used for the parabolic bodies was also used for the cone-cylinder bodies. The base drag was assumed to be equal to zero for all fineness ratios. The lowest value of fineness ratio (11.2) for which calculated drag is shown represents a cone-cylinder body with a zero-length cylindrical section.

The calculated total drag has approximately a straight-line variation with fineness ratio. The viscous drag is the largest component part and represents from 30 to 60 percent of the total drag.

Comparison of the Parabolic and Cone-Cylinder Bodies

Figure 8 indicates that the drag coefficients (based on frontal area) of both parabolic and cone-cylinder bodies have similar trends at supersonic speeds with Mach number and fineness ratio. For the fineness ratios considered, however, the parabolic bodies have between 9 and 18 percent less drag than the cone-cylinder having the same volume and maximum diameter.

The previously discussed calculated and experimental drag coefficients (based on frontal area) of the parabolic and cone-cylinder bodies at $M = 1.4$ are shown in figure 10(a) for purposes of comparison. The calculated curves indicate that, for fineness ratios greater than 15, the parabolic body has less drag than the cone-cylinder body having the same fineness ratio. For fineness ratios less than 15, the calculated curves indicate the cone-cylinder bodies have the lesser drag; however, experimental drag values to substantiate this point are not available.

In order to have a volumetric comparison of the two types of bodies the same data (based on the 2/3 power of volume) are presented in figure 10(b). On the volume basis the parabolic bodies have consistently lower drag than the cone-cylinder bodies having the same fineness ratio.

The calculations indicate a tendency for the drag difference to become small at the higher fineness ratios. Experiment and calculations show that the drag coefficient decreases for both bodies with increasing fineness ratio.

CONCLUSIONS

Flight tests at supersonic speeds and zero lift of bodies of revolution with fineness ratios from 6 to 25, having parabolic and cone-cylinder profiles, and having a base to maximum diameter ratio of 0.437 lead to the following conclusions:

1. Parabolic bodies having nearly optimum location of maximum diameter (0.6 body length) have least drag for values of fineness ratios in the range from 9 to 18. The minimum drag coefficient (based on frontal area) is approximately 0.14.

2. At fineness ratios between 17 and 25, parabolic bodies have between 9 and 18 percent less drag than 8° cone-cylinder bodies having the same volume and maximum diameter.

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1. Hart, Roger G., and Katz, Ellis R.: Flight Investigations at High-Subsonic, Transonic, and Supersonic Speeds to Determine Zero-Lift Drag of Fin-Stabilized Bodies of Revolution Having Fineness Ratios of 12.5, 8.91, and 6.04 and Varying Positions of Maximum Diameter. NACA RM L9I30, 1949.

2. Welsh, Clement J.: Results of Flight Tests to Determine the Zero-Lift Drag Characteristics of a 60° Delta Wing with NACA 65-006 Airfoil Section and Various Double-Wedge Sections at Mach Numbers from 0.7 to 1.6. NACA RM L50F01, 1950.

3. Von Kármán, Theodor, and Moore, Norton B.: Resistance of Slender Bodies Moving with Supersonic Velocities with Special Reference to Projectiles. Trans. A.S.M.E., vol.54, no. 23, Dec. 15, 1932, pp. 303-310.

4. Van Driest, E. R.: Turbulent Boundary Layer for Compressible Fluids on an Insulated Flat Plate. Rep. No. AL-958, North American Aviation, Inc., Sept. 15, 1949.

$$\frac{L}{D} = 17.78$$
$$K = 0.6$$

Fin profile
A - A

$$\frac{L}{D} = 24.5$$
$$K = 0.6$$

(a) Parabolic bodies.

Figure 1.- General arrangement of model configurations tested, including
rocket case, blast tube, and nozzle. All dimensions are in inches
unless otherwise noted.
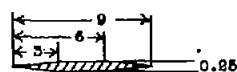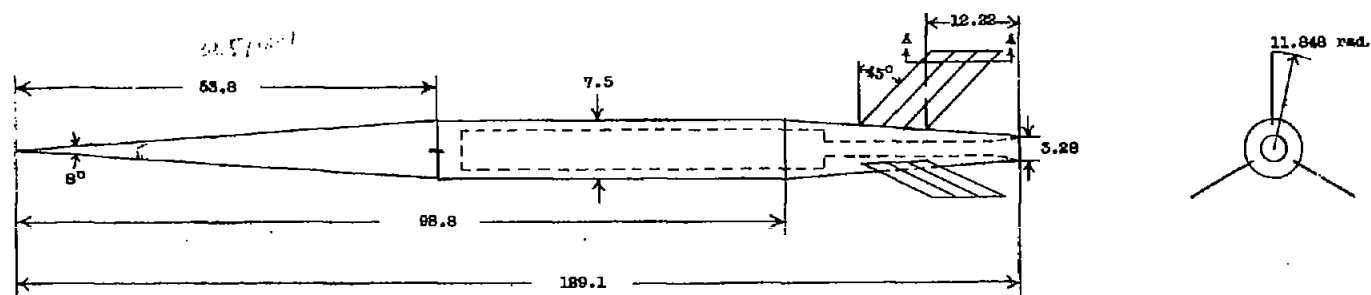
Fin profile
A - A
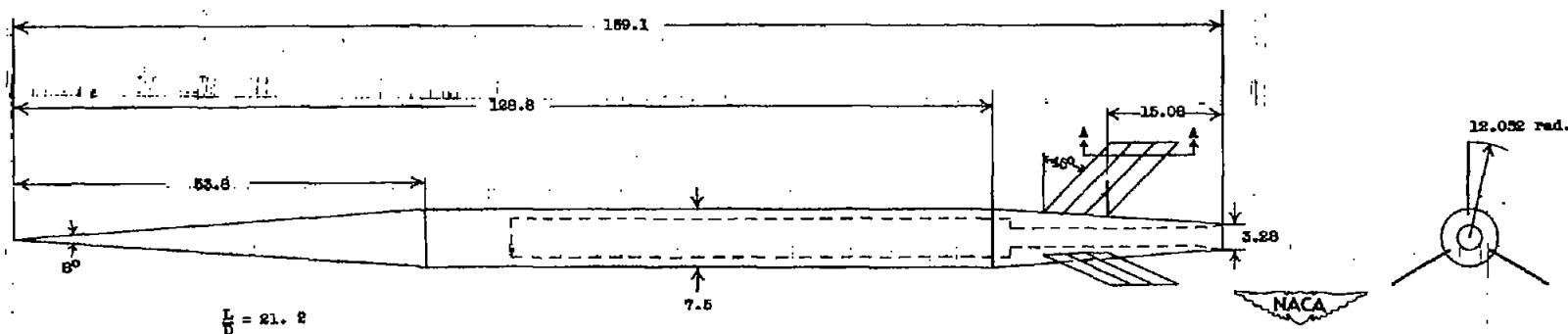
(b) Cone-cylinder bodies.

Figure 1.- Concluded. All dimensions are in inches unless
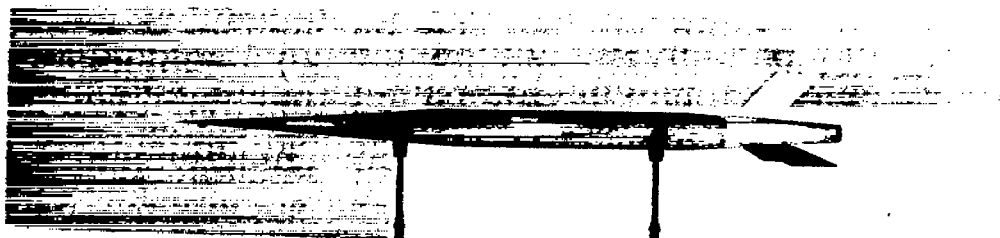otherwise noted.
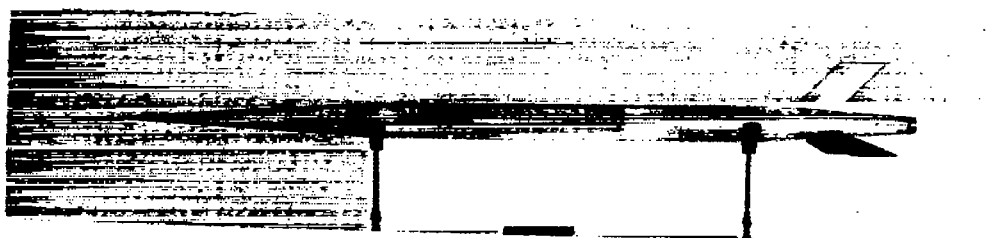
CONFIDENTIAL
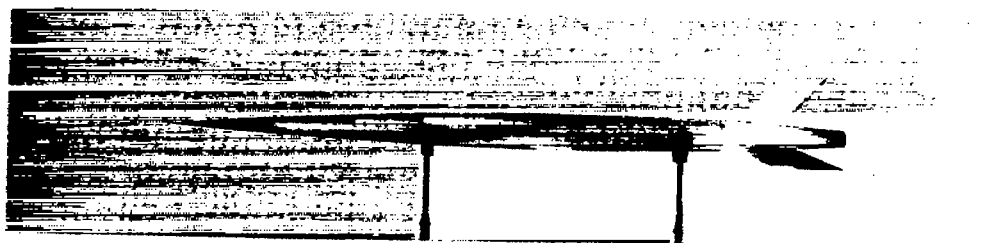
$$\frac{L}{D} = 17.78$$
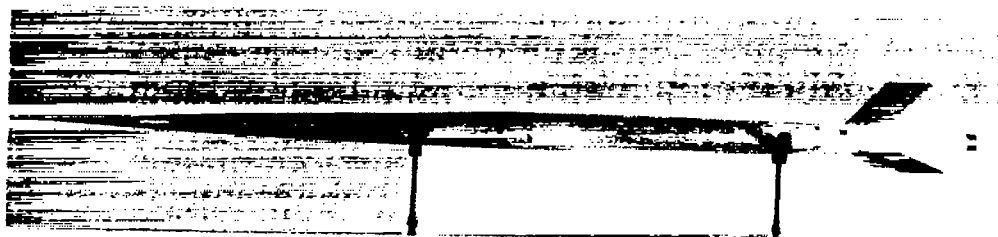
$$\frac{L}{D} = 24.5$$

(a) Parabolic bodies.

$$\frac{L}{D} = 17.2$$

$$\frac{L}{D} = 21.2$$

(b) Cone-cylinder bodies.

Figure 2.- Side views of model configurations tested. L-70766

CONFIDENTIAL

Blast tube

1/4 O.D.
pressure
tube

2.48

11.75

CONFIDENTIAL

CONFIDENTIAL

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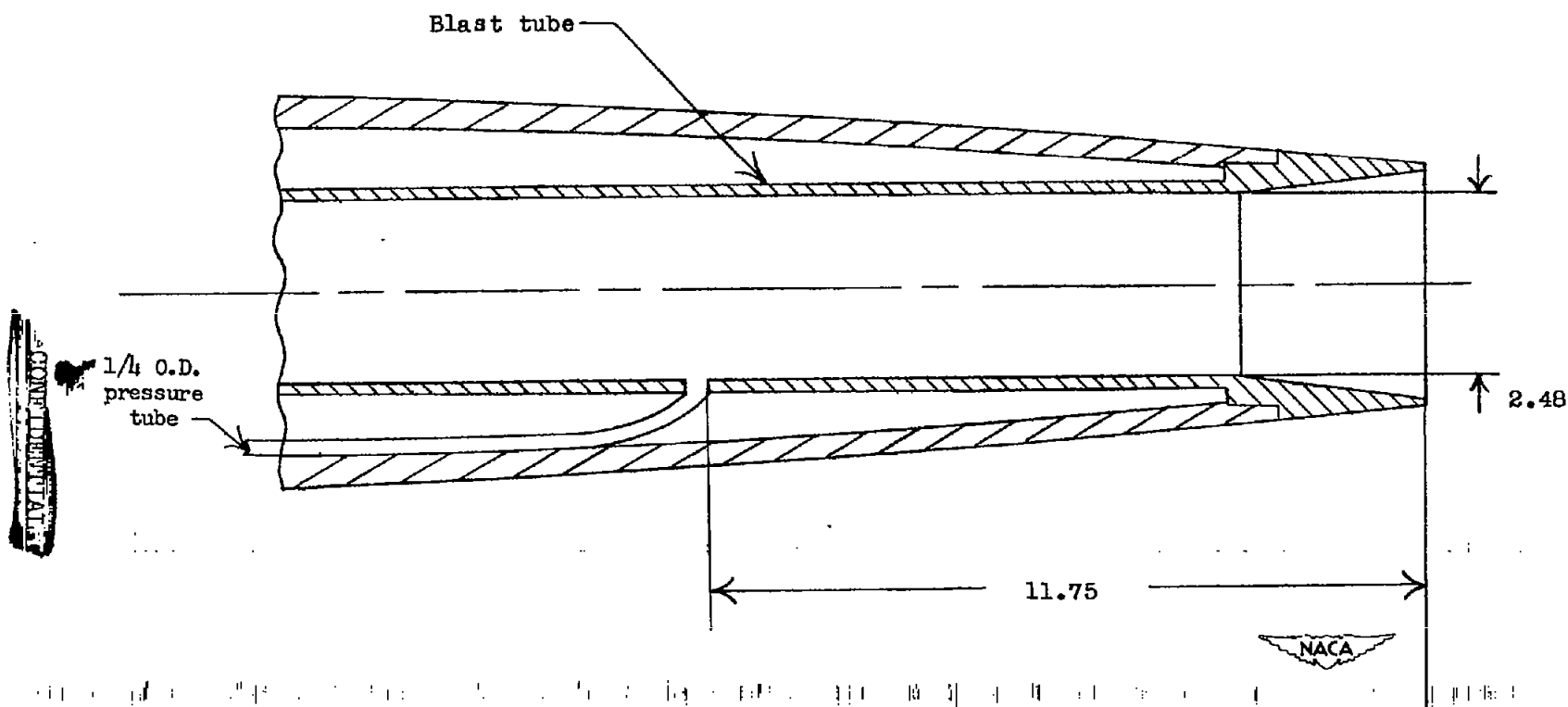
Figure 3.- Sketch of body base-pressure-tube installation for the
parabolic bodies tested. All dimensions are in inches.

CONFIDENTIAL
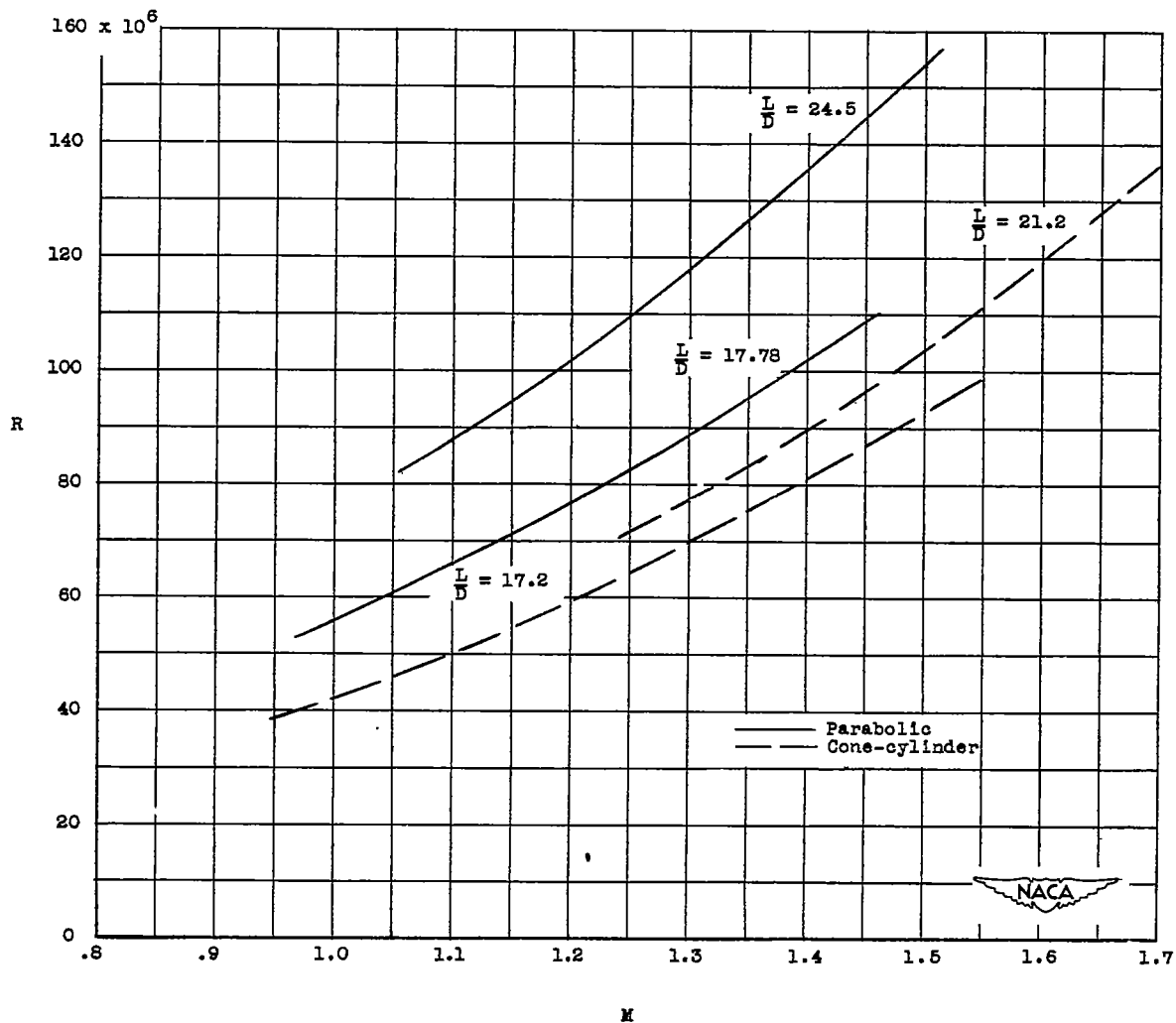
Figure 4.- Variation of Reynolds number in flight, based on body length, with Mach number for bodies tested.
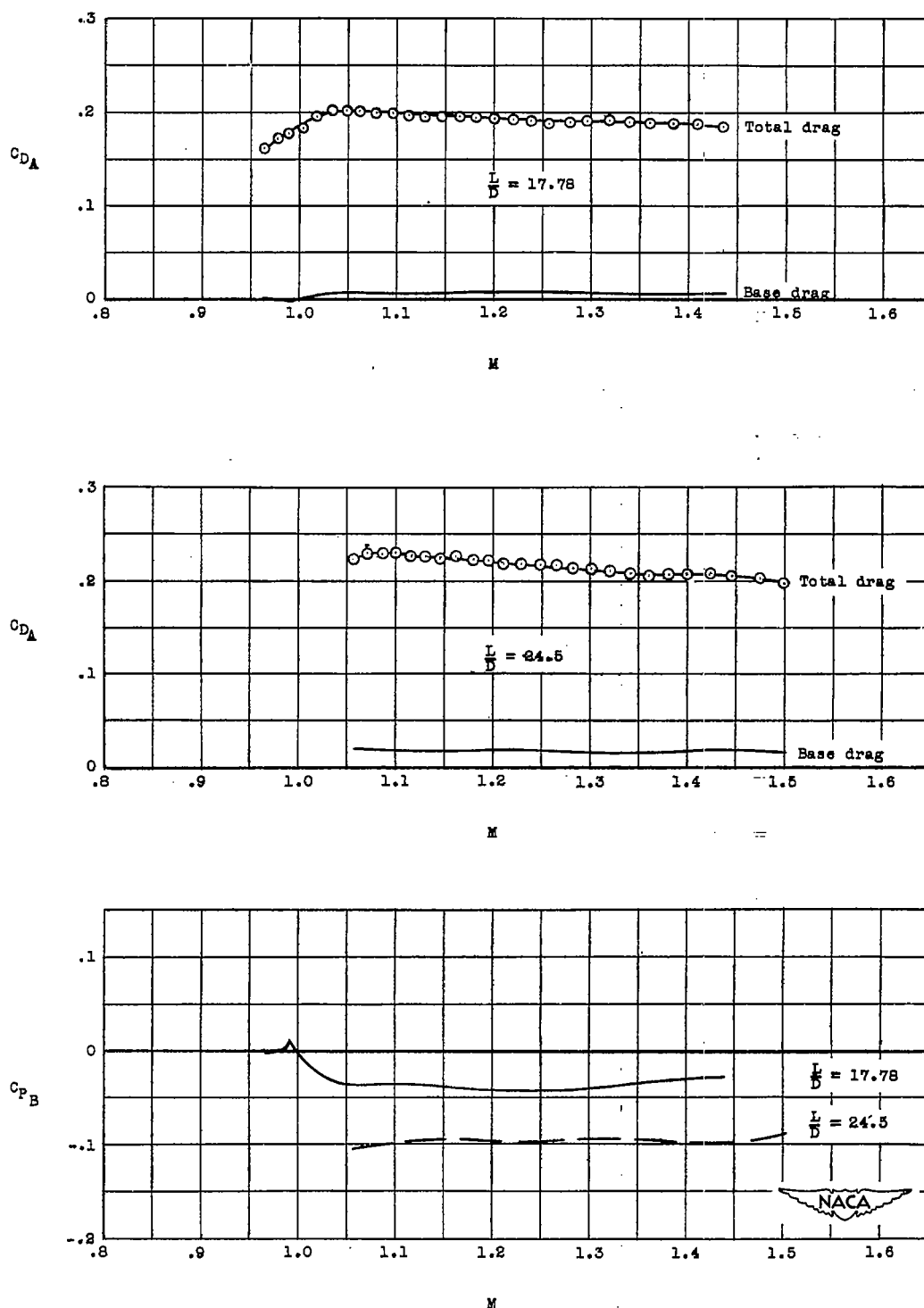
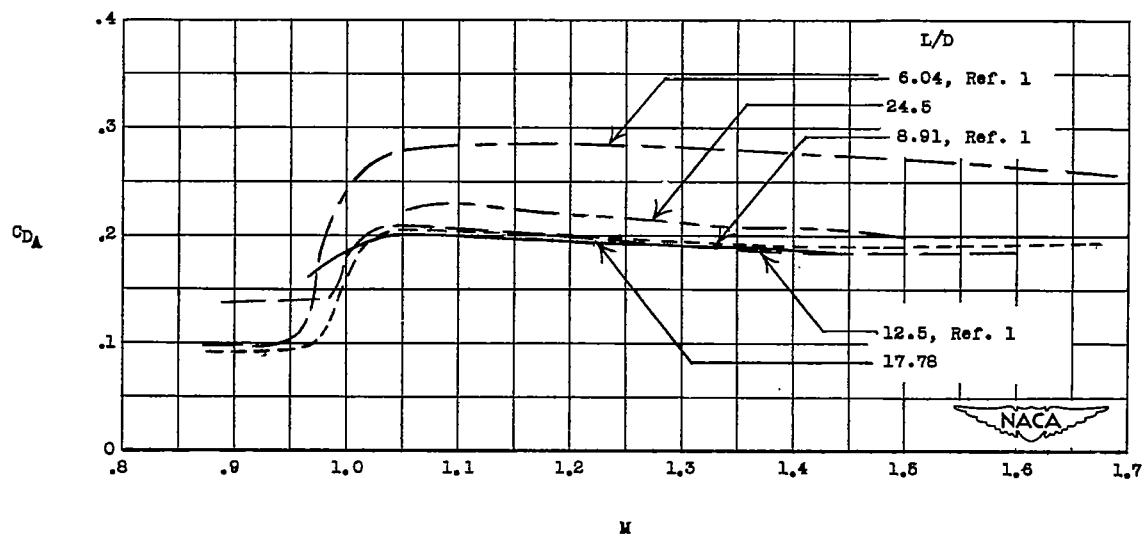Figure 5.- Variation of total drag coefficient, base drag coefficient, and base pressure coefficient with Mach number for the fin-stabilized parabolic bodies tested.

Figure 6.- Comparison of experimental drag coefficients, based on frontal area, for fin-stabilized parabolic bodies.
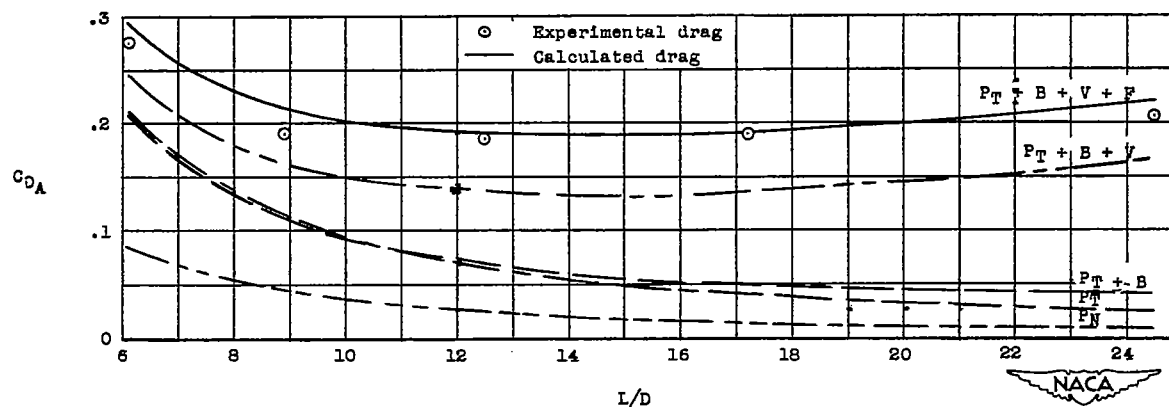

Figure 7.- Variation of experimental and calculated drag coefficients based on frontal area with fineness ratio at M = 1.4. Component parts of the calculated drag are also shown. Fin-stabilized parabolic bodies.
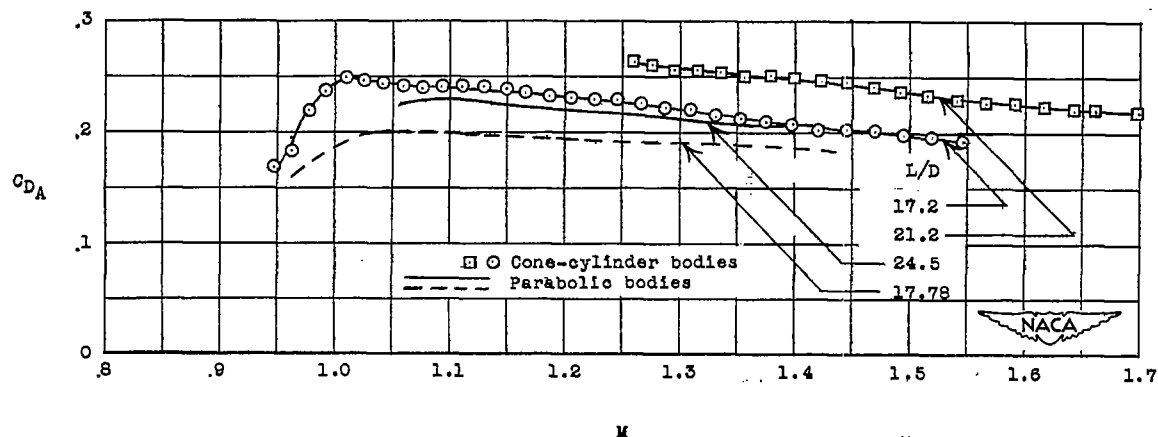
Figure 8.- Comparison of experimental drag coefficients based on frontal area for fin-stabilized cone-cylinder and parabolic bodies.
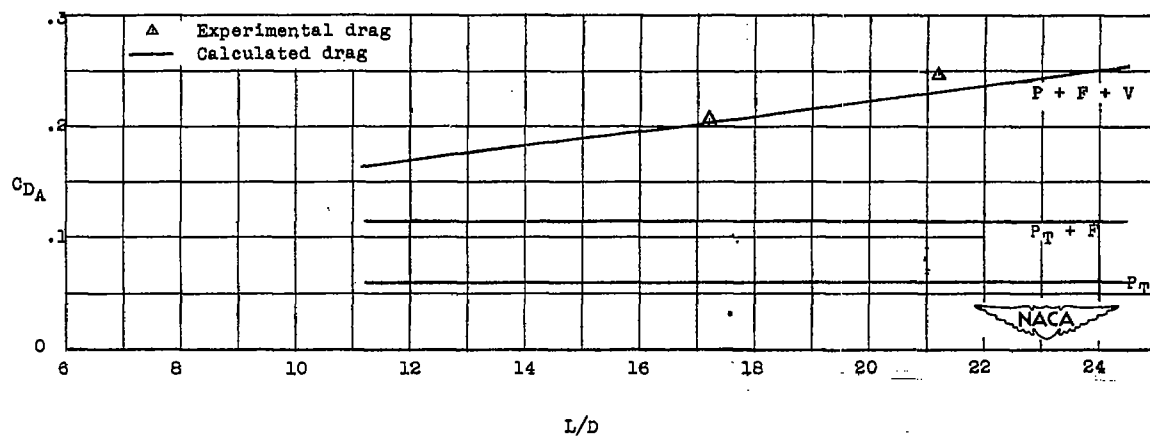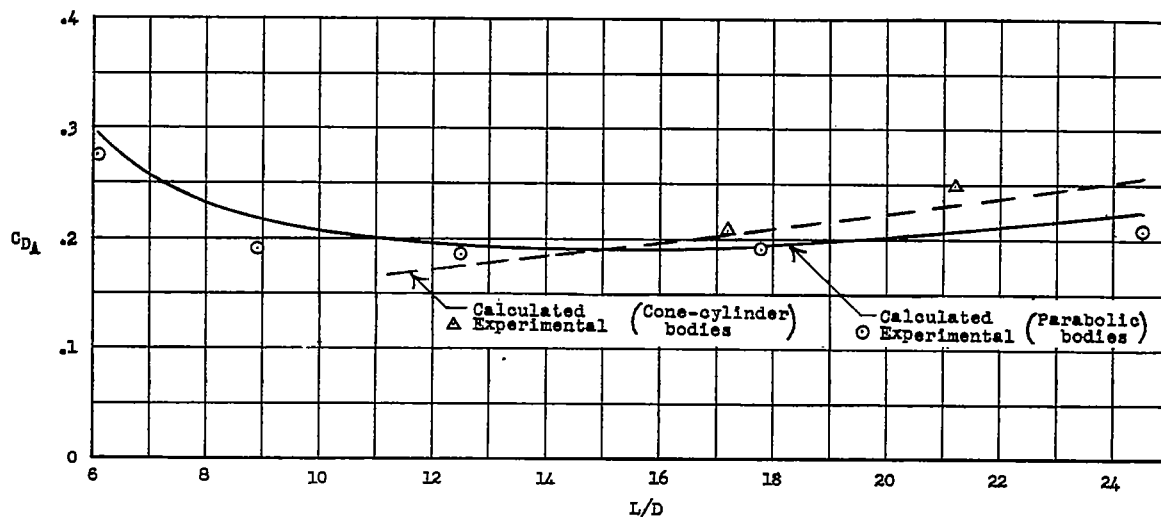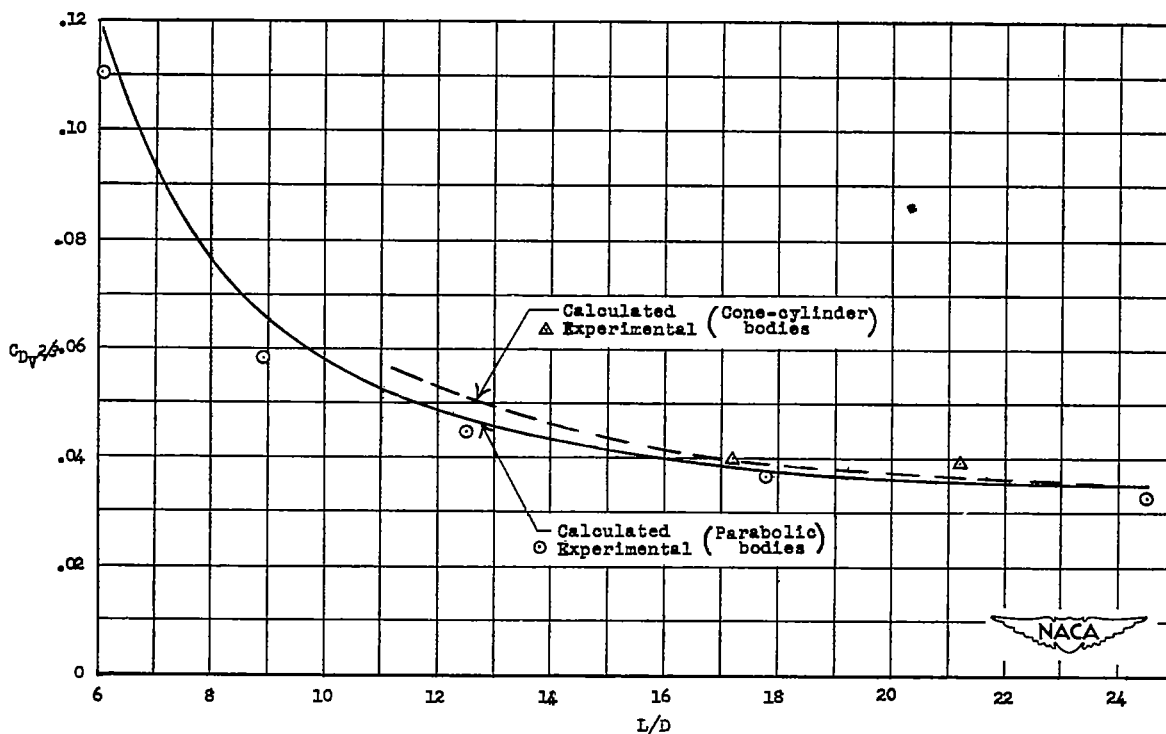

Figure 9.- Variation of experimental and calculated drag coefficients based on frontal area with fineness ratio at M = 1.4. Component parts of the calculated drag are also shown. Fin-stabilized cone-cylinder bodies.

(a) Coefficients based on frontal area against fineness ratio.

(b) Coefficients based on volume$^{2/3}$ against fineness ratio.

Figure 10.- Experimental and calculated drag coefficients for fin-stabilized cone-cylinder and parabolic bodies at M = 1.4.